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Stature estimation based on radial and ulnar lengths using three-dimensional images from multidetector computed tomography in a Japanese population

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ABSTRACT

The aim of our study was to evaluate correlations between cadaver stature (CS) and radial and ulnar lengths based on three-dimensional (3D) computed tomography (CT) images, and to develop modern regression equations for estimating CS in a Japanese population. Measurements were performed on 245 Japanese subjects (123 males and 122 females) who underwent postmortem CT between May 2011 and December 2013. A 3D reconstructed image was used for assessment. The linear distances of the left radial (LR) and right radial (RR) lengths were measured as a straight-line distance from the most anteroproximal point of the head to the most distal end of the styloid process. The linear distances of the left ulnar (LU) and right ulnar (RU) lengths were measured as a straight-line distance from the most posteroproximal point of the olecranon to the most distal end of the styloid process. The correlation between CS and each parameter (LR, LU, RR, and RU) was assessed using Pearson product-moment correlation coefficients and regression analysis was performed for stature estimation. There were significant correlations between CS and each parameter regardless of sex, indicating that the radial and ulnar lengths measured on 3D CT images can be predictive of stature estimation. Simple regression equations for stature estimation calculated from LR provided the lowest standard error of estimation (SEE) (all subjects, SEE = 4.18 cm; males, SEE = 4.09 cm; females, SEE = 4.21 cm). In addition, multiple regression equations were more accurate and reliable than the single linear regression equations.

1. Introduction

The personal identification of skeletonized or decomposed human remains is a crucial task in the field of forensic investigation. Along with sex, age, and ancestry, stature is an important component of the biological profile that characterizes individuals and can be evaluated from the skeleton even after many years have passed [1–3]. These parameters enable forensic investigators to narrow down the pool of missing person's profiles and allow more definitive markers, such as DNA, to be used for final identification confirmation [4].

Mathematical methods that require data collected from only a few skeletal elements are commonly used to estimate stature based on the sex- and population-specific regression formulae derived from the correlation between stature and the measurements of some skeletal elements. Many previous studies using the measurements of the extremities have accurately estimated stature from long bone regression equations [5,6]. The long bones are mainly composed of hard tissues; thus, these skeletal elements are most frequently found even after centuries have passed [7]. In addition, previous studies have revealed that the length of long bones can be used to predict stature even if only parts of the human body or fragments of bone are available for analysis [5,8].

Stature varies across populations and is determined by genetics, geographical location, environment, and climatic conditions [9]. In addition, an equation based on data from one ethnic group is not always applicable to another because the proportion of limb bone length to stature also varies among populations [10]. Therefore, the development of population-specific methods is necessary, and many equations describing the relationship between stature and

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radial and ulnar lengths from various populations have been published [3,11–15].

In 1960, Fujii [16] derived regression formulae for stature estimation in a Japanese population by analyzing the correlation between stature and each long bone, and in 1986, Yoshino et al. [17] measured long bone lengths, including externally measuring the radius and the ulna of living adults, and constructed formulae for stature estimation. To date, the formulae from these two studies have been commonly used in Japan, even though several decades have passed since these reports were published. The proportion of extremities to stature in the Japanese population has changed, potentially due to because of westernized influences including nutrition and lifestyle [18], and thus the previous equations for stature estimation may possibly yield large deviation when current data are applied to them. Therefore, estimation formulae based on contemporary data should be added to current forensic anthropological knowledge. Recently, Hasegawa et al. [19] constructed precise prediction formulae based on the lengths of the femur, tibia, and humerus using dual-energy X-ray absorptiometry based on contemporary data from Japanese individuals. However, our search of the literature revealed that the correlation between stature and the lengths of the radius and ulna using contemporary data has not been investigated. Prediction formulae based on regression analysis of bones other than lower limb bones are important for stature estimation in the event that lower limb bones of human remains are not available for investigation.

The aim of this retrospective study was to assess the correlation between stature and length of the radius and ulna using three-dimensional (3D) computed tomography (CT) images and to develop regression equations for estimating stature in a modern Japanese population.

2. Materials and methods

The experimental protocol was approved by the Ethical Review Board of the Graduate School of Medicine, Chiba University, and did not require approval of the subjects' next of kin.

We reviewed contemporary data from 245 cadavers of known age who underwent postmortem CT with subsequent forensic autopsy at the Department of Legal Medicine at Chiba University between May 2011 and December 2013. The subjects included 123 males (20–91 years, mean: 60.3 ± 17.4 years) and 122 females (19–95 years, mean: 61.7 ± 19.5 years). Subjects were excluded if their medical history highlighted conditions or events that could have affected stature or the upper limbs; cases of any acquired or congenital deformities, fracture, burning, or trauma were excluded from this study.

First, the cadaver was supine in full extension, and a measuring tape was used to measure the length between the skull vertex and the heel in millimeters (mm) to determine the cadaver stature.

Postmortem CT was performed with a 16-row detector CT system (Eclos; Hitachi Medical Corporation, Tokyo, Japan). The scanning protocol was as follows: 1.25 mm collimation, 1.25 mm reconstruction interval, 120 kVp tube voltage, 200 mAs tube current, and a rotation time of 1 rotation per second; a hard filter was also used. Image data were processed on the Synapse Vincent workstation (Fujifilm Medical, Tokyo, Japan) to obtain orthogonal multiplanar reconstruction images and volume-rendered images.

A 3D reconstructed image was used for assessment. The left radial (LR) and right radial (RR) lengths were measured as a straight-line distance from the most anteroproximal point of the head to the most distal end of the styloid process (Fig. 1a and b). The left ulnar (LU) and right ulnar (RU) lengths were measured as a straight-line distance from the most posteroproximal point of the olecranon to the most distal end of the styloid process (Fig. 1c and d). These measurements were conducted using electronic cursors and recorded to the nearest 0.1 mm. To assess intraobserver and interobserver errors, the four parameters (LR, LU, RR, and RU) were measured again by both the original researcher and another researcher using 30 randomly selected images.

Statistical analyses were performed on a personal computer using Statistical Package for the Social Sciences (SPSS) version 21.0 computer software (IBM Corp., Armonk, NY). The range, mean, and standard deviation of the four parameters were calculated for all subjects and then separately for male and female subjects. The Mann–Whitney *U* test was used to evaluate differences in age, stature, and the parameters between male and female subjects. The Mann–Whitney *U* test was also used to compare the LR with RR, and the LU with RU to determine if bilateral differences exist. The Wilcoxon test was used to estimate the degree of intraobserver and interobserver error. Pearson product-moment correlation coefficients (r) were calculated to assess the correlation between stature and each of the four parameters. The significance of each correlation was evaluated by Student's t-test. P values less than 0.05 were considered statistically significant. Simple linear regression equations were calculated for each of the four parameters to estimate stature. Multiple stepwise linear regression equations including all the four parameters were also calculated to derive the most accurate formula. The significance of the regression equation was assessed using the coefficient of determination and the standard error of estimation (SEE).

3. Results

Table 1 shows descriptive statistics of age, stature, and the four parameters. The Mann–Whitney *U* test revealed that males were significantly taller than females, and all four parameters in males were significantly larger than those in females. However, no significant difference in age distribution between males and females was found. No significant difference between the LR and RR (all subjects, $P = 0.901$; males, $P = 0.670$; females, $P = 0.841$) or the LU and RU (all subjects, $P = 0.510$; males, $P = 0.579$; females, $P = 0.420$) were also found. The Wilcoxon test revealed no significant intraobserver error (LR, $P = 0.763$; LU, $P = 0.552$; RR, $P = 0.702$; RU, $P = 0.576$) or interobserver error (LR, $P = 0.692$; LU, $P = 0.524$; RR, $P = 0.675$; RU, $P = 0.538$).

Table 2 illustrates the correlation coefficients between stature and each of the four parameters for all subjects, males and females, respectively. Fig. 2 shows plots comparing stature with each parameter. All measurements were significantly correlated with stature ($P < 0.001$). The correlation coefficients calculated using radial measurements (the LR and RR) were higher than those calculated using ulnar measurements (the LU and RU). The highest correlation coefficient was observed for the LR in all cases (all subjects, $r = 0.914$; males, $r = 0.838$; females, $r = 0.852$), whereas the lowest correlation coefficient was observed for the RU among both sexes (all subjects, $r = 0.889$; males, $r = 0.788$; females, $r = 0.821$). The correlation coefficients between stature and all four parameters were higher for females than for males.

Table 3 shows the simple linear regression formula, SEE, and coefficient of determination derived from each of the parameters for stature estimation among all subjects, and then for males and females, separately. The SEE values ranged from 4.18–4.72 cm for all subjects, 4.09–4.58 cm for males, and 4.21–4.58 cm for females. From the simple linear regression equations, the SEE values calculated for males were slightly lower than those for females.

Table 4 shows the results of the multiple regression analysis. The multiple regression analysis presented higher coefficients of determination (from 0.839–0.831 for all subjects, 0.706–0.690 for males, and 0.735–0.722 for females) and slightly lower SEE values